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Neutron Tomography at the Los Alamos Neutron Science Center

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Abstract

Neutron imaging is an incredibly powerful tool for non-destructive sample characterization and materials science. Neutron tomography is one technique that results in a three-dimensional model of the sample, representing the interaction of the neutrons with the sample. This relies both on reliable data acquisition and on image processing after acquisition. Over the course of the project, the focus has changed from the former to the latter, culminating in a large-scale reconstruction of a meter-long fossilized skull. The full reconstruction is not yet complete, though tools have been developed to improve the speed and accuracy of the reconstruction. This project helps to improve the capabilities of LANSCE and LANL with regards to imaging large or unwieldy objects.

Neutron Tomography at the Los Alamos Neutron Science Center

Introduction

My initial project was to integrate the detector software used on several of the neutron beamlines at the Los Alamos Neutron Science Center (LANSCE) with the status of the accelerator. As part of this, I was tasked with a tomographic reconstruction of data from one of the beamlines (4FP60R at the Weapons Neutron Research facility). This secondary project was more involved than it initially appeared, and consumed the majority of my time. My interest in both problems is a desire to gain a broad and in-depth understanding of topics in computer science and electrical engineering.

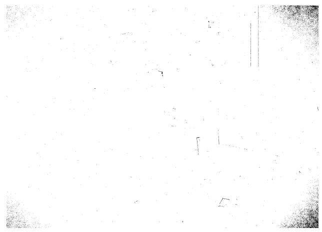
Description

The purpose of my initial project was to integrate detector software, similar to that used for commercial X-ray tomography, with the status of the neutron beam provided by an accelerator-driven pulsed neutron source. Currently the data acquisition system is totally decoupled from the status of the beam, which fluctuates and can drop out in the middle of an acquisition sequence. This, in the case of a tomography, causes dark images, anomalous features, and intensity variations between images, which all contribute to poor quality reconstructions, when reconstruction is possible from the incomplete data. To combat this, the current procedure is to scan the object twice, in the hope that if the beam is off during a portion of the scan, it will not be off during the second pass. This work-around also poses its own problems, with scans taking twice as long to complete, and difficulties caused by longer term fluctuations in beam current modulating the intensity of 'matching' images in a single series.

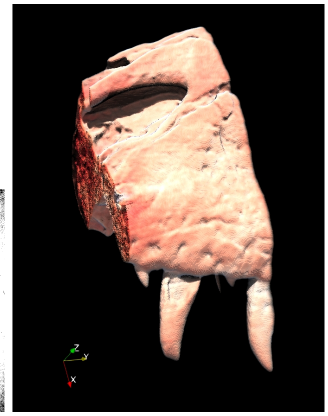
As part of this, I began working on what was originally a side project to get a handle on the difficulties this lack of integration posed. This project was a tomographic reconstruction of a set of data of a tyrannasaurid skull, that of *Bistahieversor sealeyi*. This fossil was part of a large specimen found in northern New Mexico in 1998, and resides at the New Mexico Museum of Natural History and Science in Albuquerque, NM. The challenge with imaging this fossil was that it is over a meter long, while the beamspot (the usable neutron beam for imaging) was approximately 20 cm by 30 cm. As such, it was the largest object that has undergone a full high-resolution neutron tomography at LANL, and was impossible to fit inside a single scan. Thus, the scan was performed in 12 different sections (Fig 1b), which needed to be stitched together for reconstruction. Due to some technical setbacks and complexities with the data, this side project became my main project over the summer.

Part of the challenge was the size - approximately 400 GB of data - combined with the nature of some of the tools. While ImageJ has scripting and macros built in, there was a limited amount of operations that could be effectively automated. Additionally, the data was quite noisy and not complete - there were missing images, with one set missing almost 10° of data in a single grouping. This requires pre-processing to remove as much noise as possible so that the reconstruction is able to succeed, since the most of the algorithms naively assume that all pixels in the input images are valid data and not noise. Thus, when the images are too noisy, the algorithms can fail to reconstruct the object entirely, producing only a field of static. When they do produce reasonable output, the noise produces noticeable 'rings' and artifacts that degrade the distinction between legitimate internal features of an object and noise.

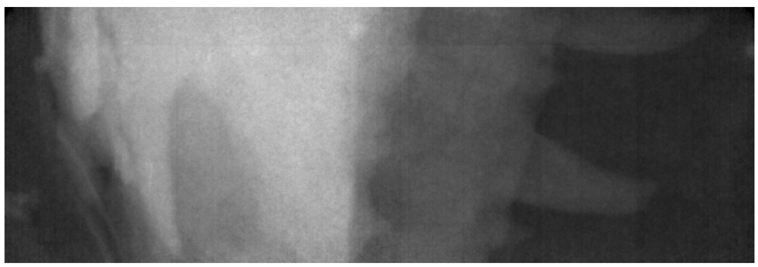
The final results are that approximately 60% of the reconstruction is complete. Along with the reconstruction, I have also developed a set of scripts both for use with and without ImageJ, that automate a variety of operations from normalizing images (via flat-field correction) to cropping images, to aligning side-by-side images automatically (using scikit-image and ORB)[1]. These are in various stages of functionality, mostly working, with even more varying states of documentation and customizability. However, these scripts should be useful and generalizable to other projects other than only this single reconstruction.



(a) Raw image from the detector



(b) One section of the reconstructed skull



(c) Image after preprocessing

Figure 1: Images from the reconstruction of the skull

Contributions to project

With regards to my initial project, I am the only team-member who was working on that, so I was wearing many hats. With regards to the tomography, I was in charge of the tomographic reconstruction portion of the project. In that position, I've reconstructed most of the neutron tomography of the dinosaur skull. This is roughly half the work of the project - the other half was acquiring the data originally - which I received over sneaker-net due to the size of the dataset.

Skills and knowledge gained

There are many tools and skills that I learned over this summer. I learned how to perform a tomographic reconstruction given the transmission data raw from the instrument. I learned how to use ImageJ, one of the main scientific image processing programs, developed as an open source project out of the National Institutes of Health. This has a very large number of plugins for everything to analyzing tomographic data, to displaying multidimensional images, to various data acquisition plugins, to tools for astronomy, MRI scans, and more. As part of my preparations from my original project, I learned quite a bit about the EPICS industrial control system, for soft real-time control of scientific instrumentation [2]. I've also learned how to use quite a few scientific computing and image processing packages in python, including numpy, scikit-image, open-cv and tomopy.

I've also gained a ton of knowledge over the summer, in so many different areas. Before this internship, I only had a vague idea what x-ray computed tomography was or how it worked. Now I understand not only x-ray tomography and neutron tomography, I also have a grasp for the different algorithms for reconstruction and challenges that occur with tomography. I also learned about the accelerator facility here at LANL. Most of what I knew about it was that it produced medical isotopes, which is only a fraction of the full uses of the facility. I now have a much better understanding of image processing works, both in the algorithmic sense and the overall process. Through this, I also gained an understanding of feature detection algorithms and the process of stitching multiple images into a single panoramic image.

Impact on academic/career planning

This internship introduced me to entire facets of my fields that I hadn't even considered. Based on work like Model-Based Iterative Reconstruction (MBIR) [3], there is still a demand for new algorithms in computerized tomography reconstruction, despite this being a field that has been in development for the last 30-odd years. Image processing, especially in real-time and embedded systems, is also a fascinating topic that I would like to look into more. I also had not realized the extent of the tools existent at LANSCE, especially those available to universities and industry - including two beamlines (4FP30R and 4FP30L) primarily utilized by electronics corporations to test semiconductors under extremely high neutron radiation. There are also students doing research on material science and physics here from all over the country.

Directly from this internship, I am considering taking a graduate-level course on mathematical physics, since it has direct applications to the topics I worked on this summer. Similarly, I am now interested in taking as many algorithmic design courses as are available at my university. I am also very interested in continuing on to do graduate work within my fields, both electrical engineering and computer science.

Relevence to the mission of the Host Agency

In the works of one of my mentors, the "image reconstruction ... advances the state of the art in imaging capabilities at LANL and is already proving useful in imaging larger programmatic items" [4]. By increasing their capabilities to handle larger objects, especially ones that require multiple scans to be stitched together, LANSCE improves their ability to perform large scale material science and non-destructive imaging research.

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